# III. NATURAL CONDITIONS AND HISTORIC CHANGES AT BIG LAGOON

## A. NATURAL PHYSICAL SETTING

The lagoon system was substantially altered throughout the 19th and 20th centuries, and limited information is available on how the lagoon functioned prior to modern times. The following interpretation of historic lagoon conditions is based primarily on the 1853 U.S. Coast and Geodetic Survey of the Pacific Coast (U.S. Coast and Geodetic Survey, 1853), supplemented by the 1858 boundary survey for Rancho Sausalito, an 1873 map prepared by the California Geological Survey, and the 1894 U.S. Geological Survey quadrangle map. Soil corings were also taken in Green Gulch pasture and the existing picnic area to provide information on historic sediments.

### 1. Geomorphic Evolution of the Site

The morphology of the lagoon was determined by the relative influence of sea level rise, sedimentation from the Redwood Creek watershed, and beach sand transport processes. Overwash sand deposited during extreme storm events would constrict the Redwood Creek outlet at the eastern end of the dune fields. As a result, winter and spring creek flows ponded behind the dune fields, creating large areas of open water and seasonal fringe wetlands.

Sea level determines the elevation at which wave action builds the beach berm, as well as the elevation of the wetland outlet. When rates of sea level rise exceeds sedimentation rates, water depths and areas of inundation increase. Following the last ice age (about ten thousand years ago), sea level rose at accelerated rates and began to inundate the areas which eventually became Big Lagoon.

Over the last 5000 years the rate of sea level rise slowed to about 0.5 feet per century. Soil corings from the Green Gulch pasture areas show lagoonal and wetland deposits persisting from prior to 3500 years ago to the mid 1800's (Figure III-2). This indicates that sedimentation rates during this period were equaled or exceeded by sea level rise. The wetland would periodically change in shape and size in response to fluctuations in sedimentation rates, but over the long term would probably maintain a configuration similar to that shown on the 1853 map (Figure III-1)

Because of the diffraction of waves around the Muir Beach headland, the lowest wave energy (and lowest beach berm elevations) occurs on the northwestern end of the beach. Therefore, the creek would enter the ocean at the low point in the beach berm. Tidal inflows would deposit sand in the lagoon opposite the inlet/outlet, building up the sand deposit which would eventually form the dune field. The high-energy wave climate would prevent vegetation from becoming established, allowing wind blown sand to build the dune field shown on the 1853 map.

In addition to long-term processes such as sea level rise and sedimentation, the lagoon system would occasionally be altered by infrequent extremely large storm floods. These events would periodically deliver large volumes of water and sediment to the system, in addition to scouring and reshaping the outlet channel.

## 2. Lagoon Morphology

Figure III-1 shows the lagoon system as depicted on the 1853 survey map. Based on the timing of the coastal surveys, this map probably shows lagoon conditions during the rainy season (between January and March). The map shows about 12 acres of open water and 13 acres of fringe wetlands in the area currently occupied by the parking lot, pastures, and riparian willows. Redwood Creek enters the wetland through a meandering delta east of its current location. This submerged delta is made up of narrow natural levees, as would be deposited by a creek discharging into a flooded wetland or backwater pond. On each side of the delta are backwater pond areas that would have been sheltered from the main Redwood Creek storm flows.

The lagoon was impounded behind a large dune field located near the current parking lot and picnic areas. The lagoon discharges into a narrow channel that flows through the southeast end of the dunes and into a tidal lagoon. Water levels in the lagoon were controlled by sand deposited in the outlet channel by wave overwash during big storms in the winter and by wind action throughout the year.

The intermittently tidal lagoon was configured much like the modern lagoon, and is shown in a typical winter high flow condition. The outlet to the ocean was at the northwest end of the beach, and is shown as about 70-feet wide on the 1853 map.

## 3. Historic Sediments

Four soil corings were taken to assist in the understanding of the evolution of the lagoon and to characterize the historic sediments and estimate sedimentation rates; a detailed interpretation of these is provided in Appendix A. Figure III-1 shows the locations of the corings, and Figure III-2 shows the measured soil profiles. The three corings in the Green Gulch pasture all show over 6 feet (2 meters) of recent sediments, fill and modern soils at the surface. The fill deposits are comprised of pebbly silty sands and sandy silts, with modern roots extending into the upper layers. Below the fill, sediments in the lower pasture coring are interbedded sands, silty sands, and silts. The low organic content of these sediments suggests that they are true lagoonal deposits between 8 and 10 feet (2.4 and 3.0 meters) depth. Between 10 and 16 feet (3 and 5 meters) depth the frequency of roots increases, suggesting that the sediments were deposited into a wetland environment with standing vegetation. The Green Gulch coring shows lagoonal sands immediately below the fill, followed by wetland sediments below 10 feet (3 meters) depth. The upper pasture coring contained wetland peats and sandy peats, indicating primarily fresh water or brackish water wetlands.

Fossils in the peat layers of the corings included root fragments, insect remains, and a common foraminifera (*Trochammina inflata*). Trochammina are common today in brackish mudflats in the San Francisco Bay. The Trochammina shells have largely dissolved, indicating frequent freshwater flushing that would dissolve the carbonate shell.

The fourth soil coring was taken in the upland area between the tidal lagoon and the parking lot. The coring is capped by about 3 feet of fill material, followed by a thick sand layer with pebbles and some organic material. This material represents a vegetated dune complex with occasional deposition of coarser gravel during storm events. At about 10 feet depth root material from Juncus species are present. The bottom of the coring was stopped at 12 feet depth by a large rock. Pebbly coarse sand above the rock represent a historic tidal or river channel, indicating that there were periods when the Redwood Creek outlet channel migrated westward of its current location.

Overall, the data from these corings show a predominantly fresh water system with brackish influence, with a mix of wetlands and open water lagoon habitat. The elevations of these deposits indicate that the bottom elevations ranged from about +1 in deep ponds to +3 feet NGVD (National Geodetic Vertical Datum) upward in the fringe wetlands.

## 4. Hydrologic Regime of the Wetland/Lagoon System

The winter 1853 map shows Redwood Creek discharging into the lagoon through a partially submerged delta. This would not be present in a fully-tidal lagoon, and indicates the lagoon was flooded in the winter by freshwater stormflows. This is verified by soil corings which contained peat layers and microfossils that would occur in a wetland frequently flushed by freshwater. These microfossils as well as the absence of willows on the 1853 map also imply that the wetland received occasional pulses of brackish water. For this to occur during high tides, ponded water elevations would have to be no higher than +3 to +4 feet NGVD.

The 1853 map shows extensive open water areas with no tules. Since tules will generally not grow in water that is greater than 2 feet deep, the bottom of the lagoon had to be at an elevation of +1 foot NGVD or lower. The soil coring from the lower pasture showed a change in the sediment stratigraphy at +0 to +1 foot NGVD, which could indicate the elevation of the bottom of the lagoon prior to filling in with modern sediment.

The channel from the wetland to the tidal lagoon would be constricted by the historic dune field. Sand transported by wind and storm events would create a hydraulic control in this channel, probably at an elevation of about +3 feet NGVD. As a result, high winter storm flows would pond behind the outlet channel and flood much of the wetland area. Water depths might range from 1 foot in the fringe wetlands to as much as 4-5 feet in the deeper ponds.

During the spring, flows would subside and the ponded areas would recede. Eventually, only areas below the outlet control elevation (+3 feet) would be ponded. Ponds would persist at depths of 2 to 3 feet throughout the summer, but would diminish when inflows were exceeded by evaporation and seepage losses (as currently occurs in the existing dredged channel). Fringe wetlands would rely on groundwater to survive the dry season. Because of the low inflow rates, the ponds would rely on wind action to provide limited circulation. In drought years there would have been periods of low dissolved oxygen.

Because of the low control elevation (+3 vs. +5 feet today), there would occasionally be tidal inflow into the wetland, especially during high spring tides. In the winter the saline water would be rapidly flushed out. In the spring and summer zones of brackish water could develop.

The intermittently tidal lagoon probably functioned much as it does today, although there is evidence that it may have been as much as 50% larger in area. Lagoon closure would occur seasonally as freshwater inflows declined and the beach berm built up. The larger tidal prism would probably not have had a significant effect on lagoon closure frequency.

### 5. Hydrology of Redwood Creek

The Redwood Creek watershed has been disturbed by grazing, logging, and water diversion over the past 200 years. The watershed has recovered to a degree today, but the runoff and erosion characteristics of the land have been significantly altered.

Under natural undisturbed conditions the watershed would infiltrate more water, and less runoff would occur during storms. As a result, winter floods would have had lower flood peaks and stream channel characteristics would have been more stable. Sediment erosion rates would have been lower, because of the relatively undisturbed soil and the stronger root structure of the native perennial grasses (which were replaced by annual European grasses soon after the land was first grazed).

Without diversions, summer flows would have been higher than they are today. In addition, the greater infiltration rates under undisturbed conditions would result in more stable groundwater levels, and droughts would have been less severe.

## B. NATURAL ECOSYSTEMS

This section describes the probable structure of the natural ecosystem in Big Lagoon in the early and mid 1800's prior to significant watershed and land use changes caused by European settlement. Unfortunately, records of floral and faunal occurrence and species abundances in these early years are sparse for Big Lagoon and Marin County in general. Most of this description is based on inferences from early Coast and Geodetic Survey maps which document topography, water ponding patterns, and large vegetation patches as well as from museum records, oral histories, and present-day vegetation and wildlife patterns along this and similar portions of the coast.

The 1853 Coast and Geodetic Survey map delineates a lagoon and marsh relatively unaltered by European settlers. The riparian forest community along Redwood Creek and Green Gulch was probably best developed upstream of Big Lagoon. The creeks opened into a single large freshwater lagoon, leading into a much smaller brackish water lagoon next to the coastal dunes. The main lagoon was mostly freshwater with occasional salt water inflows from winter storms. Even episodic inputs of salt water can have profound impacts on wetland community structure, especially of plants (Zedler 1984). The wetland habitats were probably surrounded by the same coastal scrub community that presently occurs along less disturbed coastal hills bordering Highway 1: for example between Muir Beach and Stinson Beach. In addition to rich aquatic communities, the historic setting included overlapping wetland and upland assemblages of birds, mammals, herpetia, and insects.

The historic flora and fauna are described from several major habitats within and around Big Lagoon: the riparian, freshwater lagoon, tidal lagoon, and upland. Within each habitat type, plant communities follow the classification and nomenclature of Holland (1986, 1990). All species are referred to by common and scientific names in the text, with two exceptions. Plants are referred to by common name, which can be cross-referenced to obtain scientific names in our tables. Birds are referred to by common name only, using the accepted nomenclature of the American Ornithologists' Union (1983, 1985). The biological monitoring program during the last year was designed to document existing patterns which might provide the greatest insight into historic ecology as well as realistic restoration options.

## 1. Riparian

The original riparian forest at Big Lagoon was probably a Red Alder Riparian Forest (Holland's element number 61130), likely a more advanced successional stage of the existing riparian thicket, which is closer to the North Coast Riparian Scrub (63100) Community. On the 1853 Coast and Geodetic Survey map, riparian forest was only illustrated at the inland edge of Big Lagoon and was probably well developed along Redwood Creek from the lagoon edge to Muir Woods. The riparian forest may have been interspersed with or bordered by a coastal swale community including monkey flower, sedges, rushes, miner's lettuce and bog lupine. Heavy pulses of flooding, prolonged seasonal inundation, and occasional saltwater inflow to the freshwater lagoon favored low marshes, and fringe wetlands.

Aquatic insects and other invertebrates in the historic riparian corridor must have been more diverse than the extant assemblages. The historic corridor was well vegetated and followed a natural path into the main lagoon with year-round flow and much larger areas of standing water. However, since the riparian habitat for aquatic invertebrates was much smaller than the freshwater lagoon habitats, aquatic invertebrates were probably best developed in the lagoon. Seasonally heavy rains and flooding would have also limited invertebrate numbers in the fast-moving stream more than in the expansive, quiet water marsh.

Records from the Marin County museum and known habitat preferences suggest that the historic Big Lagoon harbored at least 10 species of amphibians and 12 species of reptiles (Table III-1). Several of the listed amphibian species, such as the yellow-legged frog (*Rana boyleii*), Ensatina (*Ensatina escholtzi*) and California slender salamander (*Batrachoseps attenuatus*), prefer the persistent fresh water and substrates in the riparian habitat, and therefore should have been most abundant outside Big Lagoon.

Relatively few species of riparian birds lived in the historic Big Lagoon because most of the riparian habitat was further inland along Redwood Creek. However, riparian habitat bordering the wetland probably provided preferred nesting habitat for some wetland-foraging species. For example, Belted Kingfishers could have nested in holes along stream banks, and Tree Swallows could have nested in riparian tree cavities adjacent to foraging areas over open water. Long-eared Owls could have nested in vacant stick nests built by other species in trees offering dense cover. Raptors present today, such as Great Horned Owls and Red-shouldered Hawks, should have been more abundant in Big Lagoon due to the availability of nearby roosting and nesting sites in riparian trees. A variety of other species could have maintained larger local populations in the Big Lagoon wetland due to an ability to exploit food resources of both wetland and nearby riparian waters: the Great Blue Heron, Green-backed Heron, Black Phoebe, Mallard, Cinnamon Teal, Gadwall and Common Merganser.

The historic abundances of species are very difficult to infer compared to simple presence. Nevertheless, since habitat area is positively correlated with both species number and abundance, the highest numbers of riparian-dependent fauna should have inhabited Redwood Creek and secondarily Green Gulch Creek, with many using and even depending on the wetland habitats of Big Lagoon.

Two large mammals no longer present undoubtedly used Big Lagoon and the immediate area. California grizzlies, the top predator in the ancient California ecosystem, foraged on the beach. Tule elk, the largest California plant eater, utilized the wetland habitat. Other smaller species, such as mountain beavers and otters, were present and used the riparian corridors. Bats relied directly on large flying insect populations from the lagoon. Numerous small mammals and their intermediate-sized predators occurred in the adjacent confer and oak forest habitats and would have used the big lagoon wetlands and riparian forest to a greater or lesser extent. This hypothetical list (Table III-2) is fairly long and reflects the likely pristine fauna of a rich mosaic of habitats including unlogged north coast coniferous forest extending into Marin County.

## 2. Freshwater Lagoon

The historic habitat of Big Lagoon was dominated by a Coastal Brackish Marsh (52200) and/or the similar Coastal and Valley Freshwater Marsh (52400). Both habitats are comprised of emergent tules, cattails, and rushes. All marsh and open water habitats indicated on the 1853 map of Big

Lagoon are now either pasture overlying sediment fill or riparian forest bordering the displaced watercourse.

Vegetation in the open water lagoon was probably patchy as a result of variable water depth, river currents, and soil stability. Large, dense patches of tules, cattails, bur-reed and rushes should have been present as in many historic California wetlands. Small herbaceous pondweeds, aquatic buttercups, and smartweeds could have rooted in shallow water. Water Fern and duckweed could have floated on the surface of quiet water.

At the edge of the open water, the marsh fringe probably harbored spike rushes, marsh pennywort, and water parsley, with tower plantain in the wetter areas. Rushes, sedges (*Carex*), silverweed, and Monkey flower probably dominated the borders of the permanent open water areas. The upper edge of the marsh was probably covered with willows, which were transitional to the riparian forest. In similar extant habitats, strong flooding periodically scours willow thickets making canopy gaps for small stands of marsh baccharis.

The historic freshwater wetland and pond must have harbored a more diverse and abundant aquatic insect fauna compared to the present. The small pond habitats that are present today contain more insect individuals, taxonomic groups, and trophic levels than the channelized and dredged portions of Redwood Creek (see Existing Conditions). The historic pond habitats were much more extensive. In addition, the high numbers of crustaceans currently associated with the ponds and emergent vegetation should have been more widely distributed and numerous under historic conditions. The elevated historic populations of insects and crustaceans should have supported many predators, particularly fish and amphibians.

Big Lagoon undoubtedly harbored several amphibian species. For example, the cattail and/or bulrush habitats within the historic Big Lagoon wetland could have been good breeding sites for the red-legged frog (*Rana aurora draytonii*), a proposed federal endangered species, since freshwater or slightly brackish water (< 4-5 ppt) was probably present in the November - March breeding season (Hayes and Jennings 1986, Jennings and Hayes, 1985). Pacific tree frogs and California newts could have also commonly bred in Big Lagoon during winter.

Even though amphibians such as the yellow-legged frog probably resided in the historic riparian habitat, and thus mostly outside Big Lagoon, the large lagoon wetland must have been an important migration and recruitment corridor between Green Gulch Creek and Redwood Creek. Ranid frogs (including red- and yellow-legged frogs) often occur in small groups or demes (Storm 1960) dependent on movement between different habitat patches. The Big Lagoon corridor should have improved interbreeding, aided restocking of naturally-disturbed habitat, and overall population resilience of riparian species.

Since reptiles are less dependent on wetlands than are amphibians, the historic Big Lagoon was probably not an important habitat for most reptile species (Table III-1). Several species could have visited the wetland and riparian edges, particularly near adjacent upland habitats, including the coast garter snake (*Thamnophis elegans terrestris*; known to commonly prey on red-legged frogs), Ensatina (*Ensatina eschscholzi*) and Slender Salamander (*Batrachoseps attenuatus*). The Western pond turtle in contrast, is an aquatic reptile and was probably common along the riparian corridors above Big Lagoon.

Bird assemblages must have been the most conspicuous fauna in the historic Big Lagoon. The large area of open water and the patch mosaic of emergent vegetation should have attracted many more breeding and wintering species and individuals than are present today. The large shallow pond should have provided foraging areas for piscivorous species such as Osprey, Belted Kingfishers, Great Blue Herons and Pie-billed Grebes. Aerial insectivores, including several swallow species and the Black Phoebe, should have been even more conspicuous than they are today because of the large ponded area.

Shallow water near marsh edges should have been heavily utilized by Mallards, American Coots, Common Moorhens, Ruddy Ducks, Great and Snowy Egrets as well as Green-backed and Black-crowned Night Herons. Common Snipes, Soras, Virginia Rails, American Bitterns, Marsh Wrens, Salt Marsh Common Yellowthroats, Song Sparrows and flocks of Tricolored and Redwinged Blackbirds should have been common residents of the marsh edge and emergent vegetation. These species could have used the low wetlands or forested riparian for nesting (Shuford 1993). Today, only Red-winged Blackbirds, Mallards and to a lesser extent Great Blue Herons and Snowy Egrets are common inhabitants of the wetland area (see Existing Conditions).

The species number and abundance of wintering and migrant waterfowl seen along coastal Marin County today (Shuford et al. 1989) probably represents a fraction of those which historically used Big Lagoon. The extensive shallow water portions of the pond and nearby edge vegetation should have supported large flocks of waterfowl such as American Widgeons, Buffleheads, Northern Pintails, Northern Shovelers, Canvasbacks, Redheads, Common Goldeneyes, Gadwalls, Green-winged, Blue-winged and Cinnamon Teal. Of these, only American Widgeons occur in significant numbers today.

Transitional willow edges, stream banks, and nearby upland scrub and riparian forests could have provided nest sites for a great variety of birds foraging in the Big Lagoon region. Yellow, Orange-Crowned and Wilson's Warblers, common yellowthroats and saltmarsh yellowthroats (a California species of concern), as well as Black-headed Grosbeaks could have nested in the dense historic willow thickets.

Known nesting and prey preferences of raptors (Shuford 1993, Mansell 1980) suggest they were common predators of rodent, bird and fish prey in the open lowland habitat of historic Big Lagoon. Short-eared Owls and Northern Harriers nest on ground covered by marsh vegetation and feed on abundant small mammal populations. Black-shouldered Kites, nesting in bushes and moderately-sized trees such as willows, also consume small mammals. Red-shouldered Hawks could have foraged in the historic wetlands for a variety of prey, including amphibians, reptiles, small mammals and insects, returning to nest sites in adjacent mature forests. Peregrine Falcons should have flourished on the abundant wetland bird prey and nested on adjacent seacliffs. Perhaps less often, Cooper's Hawks, Kestrels, Red-tailed Hawks, Long-eared Owls, Great Horned Owls and Turkey Vultures would have foraged in the wetlands, joined occasionally by California Condors (apparently last sighted at Mt. Tamalpais in the 1950's; Evans 1988).

### 3. Tidal Lagoon

The historic intermittently tidal lagoon occurred in the same general location as it does today. Most of the lagoon was covered with shallow, open water habitat, shifting seasonally from fresh water to brackish water. Northern Coastal Salt Marsh (52110) probably covered a very small area immediately north of the brackish lagoon. The physical environment was probably too dynamic for extensive salt marsh development due to storm waves, strong currents from creek flooding, and wind-blown sands. Well developed pickleweed and cord grass communities were probably not present here. Instead, the present complement of species likely dominated the historic salt marsh: silverweed, rushes, and small patches of pickleweed, salt grass, jaumea, and alkali heath.

Salt marsh fauna were probably an insignificant part of the historic Big Lagoon ecosystem, reflecting the small size of this habitat. Black Rails, Clapper Rails and Savannah Sparrows were probably rare here for the same reason.

The historic tidal lagoon probably harbored similar species of insects, crustaceans, and annelid worms to those present today. However, since the historic region of seasonal brackish inflow to the large freshwater lagoon was so much larger than today, the benthic and swimming fauna of the tidal lagoon was probably more widespread and abundant in the past. The same is likely true for the brackish and freshwater fishes using the tidal lagoon. Birds, on the other hand, were probably more a mixture of those using the beach and the Big Lagoon wetlands.

### 4. Upland: Beach Dunes and Hillsides

The sand dune plant community was probably a Northern Foredune (21210) Type, possibly grading shoreward into the perennial-dominated Northern Foredune Grassland (21211) and/or Central Dune Scrub (21320). Intensive dune erosion by winter waves and floods probably kept the dune plant communities at an early successional state, much as they are today (although the lack of foot traffic would have improved conditions for plants).

The Northern Foredune would have been vegetated by short-lived herbaceous species such as those currently present: beach bur, beach sagewort, and beach saltbush. Before the dunes were grazed or trampled, they could have supported the once-widespread Northern Foredune Grassland. This habitat, which is now rare, was dominated by dune bluegrass and American dune grass. More protected than the foredune flora, the Central Dune Scrub was probably composed of woodier shrubs such as lizard tail, lupines, mock heather and coyote brush. These plants were probably present mainly at the sheltered southeast corner of the beach. Here they could have competed with coastal scrub species along the steep hillsides.

The intermittent sand dune and beach habitat at the mouth of Big Lagoon probably provided a relatively small area for roosting and feeding by a variety of gulls, Brown Pelicans and shorebirds. The threatened Snowy Plover may have nested on the historic beach, however the relatively flat and dry areas within the dunes, the preferred nesting habitats, probably covered a very small area of the historic beach, as they do today. Muir Beach is also subjected to frequent wave disturbance washing over most of the low dunes and into the tidal lagoon. Other beaches to the north, Stinson Beach spit and Point Reyes Beach, where Snowy Plover nests have been documented in recent years (Shuford 1993) were probably always much more important breeding sites.

Though the historic dune community supported a small insect and reptilian fauna, they were probably not diverse or abundant due to the small habitat size and especially the over-wash from storm waves.

Historic dune and lowland communities probably graded into hillsides of Northern Coastal Coyote Brush Scrub (32120) and/or the intergrading Coastal Sage Chaparral Scrub (37600). These communities were comprised of numerous "soft chaparral species" including California sage, Black sage, bush monkey flower and poison oak. Occasional seeps or moist areas on the hillsides (Freshwater Seeps: 45400), could have supported low-growing perennial herbs, especially sedges and grasses.

The upland coastal scrub and chaparral communities typically support fewer bird species and individuals than the complex riparian and low wetland systems. Therefore, though the hillsides supported a larger native avifauna than currently exist, it was much smaller and less diverse than the birds of Big Lagoon. Notably, raptors such as hawks, owls, California Condor and Peregrine Falcon undoubtedly foraged in both hillside and wetland habitats.

## 5. Historic Fisheries

Historic fish species composition of Redwood Creek probably differed little from that observed today. As a coastal stream, Redwood Creek should have contained only fish species able to enter the watershed through salt water. These species would have included steelhead (*Oncorhyncus mykiss*), coho salmon (*O. kisutch*), threespine stickleback (*Gasterosteus aculeatus*), prickly sculpin (*Cottus asper*) and coastrange sculpin (*C. aleuticus*); all of these species are still present. Riffle sculpin (*C. gulosus*) are also present in Redwood Creek, especially upstream near Muir Woods National Monument. Riffle sculpins normally are absent from small, isolated coastal streams, so they may have been introduced.

Prior to the filling and other modifications of the lagoon- estuary at the mouth of Redwood Creek, the habitat conditions of "Big Lagoon" probably varied substantially seasonally and among years.

In years when the lagoon closed late in summer, or when summer streamflows were low, the summer lagoon probably remained brackish all summer. Although the system was probably shallow (< 2 m), it may have been stratified and warm during the summer of those years, providing marginal habitat for steelhead and coho. In years when the lagoon closed earlier, or when summer streamflows were more abundant, the lagoon was probably deeper and was converted to freshwater by inflows; in those years the lagoon would have been cooler and provided good rearing conditions for juvenile steelhead, and possibly for salmon. The larger lagoon probably also provided habitat for tidewater goby (*Eucyclogobius newberryi*), which are not now present. Juvenile staghorn sculpin (*Leptocottus armatus*) and starry flounder (*Platichthys stellatus*), hatched in the ocean, may have reared in abundance in the summer lagoon. Other marine fishes, including shiner surf perch (*Cymatogaster aggregata*), topsmelt (*Atherinops affinis*), and Pacific herring (*Clupea harengus*), may have used the lagoon for feeding and spawning.

## C. HISTORIC CHANGES

### 1. Land Use Changes

Prior to the arrival of the Spaniards the impacts of human activity in the area were limited, and Big Lagoon and the Redwood Creek watershed were shaped primarily by natural processes. Two shell mounds have been identified at Big Lagoon, indicating that the area was used by Native Americans as foraging grounds and a seasonal camp. Native Americans were also known to use controlled burns to shape vegetation patterns in the region.

The Spaniards established the Presidio at San Francisco in 1776. The Spanish did not use Marin County for grazing or agriculture until the Mission San Rafael was established in 1817. The mission recorded having 8,000 cattle, horses, and other grazing animals (Munro-Fraser, 1880). During this period portions of the Redwood Creek watershed were probably used for cattle grazing and logging. In 1838, William Richardson was granted Rancho Sausalito by the Mexican governor in San Francisco. The Rancho boundaries extended from the southern tip of Marin County to Mount Tamalpais, and included the Redwood Creek watershed. Richardson was reported to graze "thousands of cattle, horses, and sheep" on his holdings (Munro-Fraser, 1880).

In 1850 California became a state and the U.S. Coast and Geodetic Survey began mapping the state and its coastal waters. In 1856 Samuel Throckmorton took financial control of Rancho Sausalito, and began running large dairy operations in the area. Throckmorton subdivided and leased the land to the Portuguese dairymen who eventually became the primary managers of the Redwood Creek watershed until the mid-20th Century (Duncan, date unknown).

By 1890 the County Road from Bolinas to Sausalito was established along the current alignment of Highway 1. In 1905 William Kent purchased Sequoia Canyon, which was donated the following year to form the Muir Woods National Monument. This protected most of the Redwood forests in the watershed from logging. In 1908 Pacific Way was extended to Muir Beach, and lots for vacation homes were developed near the confluence of Fern Creek and Sequoia Canyon. The Mount Tamalpais Sportsmens Club began impounding the lower reaches of Redwood Creek to enhance trout fishing.

In the early 1900's a small house and structures were constructed adjacent to Redwood Creek, and levees were constructed to reduce flooding. By the 1920's an inn and series of small cottages was operating at Muir Beach, and a 150-foot pedestrian bridge crossed the tidal lagoon to the beach. During this period the improvement in roads and increase in the Bay Area population resulted in increasing recreational use of the beach and watershed. This was also the period in which subdivision and home-building began to occur within the community of Muir Beach (Duncan, date unknown).

During the 1930's the family-owned dairies were still the primary land use on private land within the watershed. Cattle grazed along the creek and hillsides up to Muir Woods. Gravel was extracted from the Redwood Creek bed by county road builders and local farmers (Banducci, personal communication). There was little or no riparian vegetation along the creek, due to grazing and clearing by the dairy farmers.

In 1945, Green Gulch and the Muir Beach areas were purchased by George Wheelwright. In the early 1960's he began to extensively modify Redwood Creek and the adjacent pasture areas downstream of Pacific Way. Modifications included construction of levees along Redwood Creek and the existing horse pasture, excavation of a large channel and construction of a dam in lower Redwood Creek, and grading and filling within the existing horse pasture. In 1967 Wheelwright donated the Muir Beach area to the State Park system, and sold Green Gulch to the Green Gulch Farm.

Kent Canyon was logged in the 1960's. In 1968 dairy operations on Redwood Creek were bought out by the government for conversion of the land to the Golden Gate National Recreation Area. From this time on cattle grazing within the watershed was phased out, ending in 1990. The state park constructed a parking lot in the current location at the beach in the late 1960's/early 1970's, and the level of the lot was raised by the GGNRA in 1981.

Currently most the of the Redwood Creek watershed is under the jurisdiction of the GGNRA and the California State Park system. Major land uses include intensive recreation at Muir Woods and Muir Beach, hiking in the backcountry, and heather and bulb farming in Franks Valley. The Green Gulch Farm occupies the Green Gulch watershed, and operates an organic farm and nursery on the valley floor. A horse riding stable operates in the former dairy buildings at the intersection of Pacific Way and Highway 1, and grazes horses in the lower portion and hillslopes of Green Gulch.

## 2. Physical Changes

The first major changes to the system resulted from grazing and logging within the watershed, starting with the first Spaniards and dairymen in the 1800's and ending in 1990. Cattle grazing damaged the hillsides and reduced vegetative cover. Grazing also virtually eliminated the perennial native grasses and replaced them with European annual grasses. Degradation of the watershed cover would have altered the hydrology, increasing the frequency and magnitude of flood flows.

The loss of vegetation and erosion of topsoil initiated the formation of gullies and landslides which in turn contributed more sediment to Redwood Creek. Increased flood flows would result in downcutting and erosion of the channel. The loss of riparian trees and other vegetation would also cause erosion and failure of the channel banks. In 1859 highly destructive fires burned on Mt. Tamalpais for 3 months, and in 1862 one of the worst floods of record occurred in California (Muir Woods archive). These floods, in combination with land disturbance from grazing and fires, would probably have delivered large volumes of sediment to Big Lagoon.

The effects of the historical sediment erosion rates can be seen in the soil corings taken in the Green Gulch pasture area (Figure III-2). Each of these corings show about 6 feet of modern soils above the historic lagoon sediments. Perhaps 1 to 2 feet of this can be attributed to fill material imported during the 1960's (Banducci, 1993), indicating that increased sedimentation in the 1800's and early 1900's deposited about 4 feet of sediment in the lagoon and creek floodplain prior to 1960. This translates to an average annual sediment deposition rate of 1,500 cubic yards per year to the lagoon system between 1853 and 1960, or about 270 tons/$mi^2$/year from the Redwood Creek watershed. This sediment deposition rate is comparable to sediment delivery rates estimated for other disturbed coastal watersheds.

The deposition of 4 feet of sediment between 1853 and 1960 greatly outpaced the rate of sea level rise (about 0.5 feet per century). As a result, the freshwater portion of the lagoon system filled in during this period. This is verified by historic accounts, in which the large pond and wetland are last seen in the 1873 California Geologic Survey maps of the area. By the time of the first U.S. Geological Survey (USGS) quadrangle maps in 1894 the entire pond area was filled with sediment, and the wetland system was primarily a delta at the confluence of Redwood and Green Gulch Creeks (Figure III-3). Until the park service took over management of the area photographs show the former pond and wetland area as grazed pastures with limited riparian and wetland vegetation.

In the early 1900's several buildings and facilities were constructed within the former wetland area. Much of the dune field was removed to provide sand for road and other construction activities, and fill was imported to raise the elevations for resort buildings near the beach. A 1946 aerial photo (Figure III-4) shows remnants of the dune field, and a broader expanse of sand between the lagoon and parking lot area. By the time of the 1965 aerial photo (Figure III-5) the fill in this area had been expanded to its current limits, and no dunes are remaining northwest of the Redwood Creek channel. Placement of this fill has allowed a salt marsh to develop adjacent to the intermittently tidal lagoon.

Sedimentation continued through the 1900's, and observations by past residents indicate that Redwood Creek downstream of Frank's Valley is 2-3 feet shallower than it was 45 years ago (Souza, personal communication). Between 1900 and 1946 Redwood Creek was rerouted towards Pacific Way and confined by levees to protect structures located on the adjacent floodplain. Fill material may also have been placed on the Redwood Creek floodplain to raise the elevations of the building foundations.

As late as 1952, the outflow of Redwood Creek into the intermittently tidal lagoon was controlled by an unvegetated sand deposit, similar to the historic outlet control. In the early 1960's George Wheelwright dredged the lower portion of Redwood Creek to form a large deep channel, in which water was impounded behind a dam near the current footbridge location. A levee was constructed separating the lower Green Gulch pastures from the Redwood Creek floodplain, and fill was brought down from the hillsides in Green Gulch to raise the pastures by 1 to 2 feet (Banducci, personal communication). Drainage from Green Gulch was rerouted into two artificial channels which drained through culverts under the levee and into the backwater section of the lower Redwood Creek channel. Most of these modifications remain in place today.

Construction of levees confined creek flows, and increased erosion of the bed. Eroded sediment would deposit behind the dam, and the lower creek channel required periodic dredging. After the dam was destroyed in the late 1970's, sediment continued to be deposited in the artificially dredged section of Redwood Creek. During the 1982 flood the entire Green Gulch pasture was inundated by several feet of water, and the pasture levee failed immediately upstream of the beach foot bridge. Large quantities of sediment were deposited in lower Redwood Creek, and a sediment delta separating the tidal lagoon from the Creek began to build up. Following this flood, the Park Service planted willows and repaired the pasture levee with gabions.

The sediment delta has continued to expand and build up in elevation, and has become established with willows and other riparian vegetation since 1982. This delta now controls the flow of water from Redwood Creek into the intermittently tidal lagoon, and backs water up into the lower portions of the creek. Its current elevation is greater than +5 feet NGVD.

Based on surveyed profiles of the creek in 1992, about 450 cubic yards of sediment have been deposited in lower Redwood Creek since George Wheelwright stopped dredging in 1970. In addition, about 1,100 cubic yards have been deposited in the delta downstream of the beach footbridge after the dam was destroyed in the late 1970's. Together these translate to an average sediment deposition rate of about 100 cubic yards per year over the last 2 decades.

Wheelwright and later the Green Gulch Farm pumped water out of the channel for irrigation until the dam was destroyed in the late 1970s. During the summer, the lower Redwood Creek channel would be pumped nearly dry. Since pumping has ceased, riparian and wetland vegetation have recovered along the channel banks.

The GGNRA phased out cattle grazing between 1970 and 1990, and the watershed has begun to recover. Riparian vegetation (alders and willows) grew in quickly along Redwood Creek. Hillside vegetation also recovered, but the grassland community remains primarily annual European grasses. Overall, sediment erosion rates from the watershed have now decreased and, while still elevated, are slowly approaching natural rates. Potential sources of erosion remaining in the watershed include the heather and bulb farm in Franks Valley, horse stable and grazing operations, various roads and trails, and agricultural activities on the Green Gulch Farm property.

In the early 1980's the beach parking lot was raised 2 to 3 feet with fill material from a nearby landslide. Prior to this time overbank flood flows from Redwood Creek were able to spill over the parking lot onto the beach. Since the parking lot was constructed, flooding has increased along Pacific Way, although the primary reason for upstream flooding is the constriction of Redwood Creek at the Pacific Way bridge and between levees downstream of Pacific Way.

## 3. Ecological Changes

### a. *Changes in Redwood Creek Watershed*

The Redwood Creek and Green Gulch Creek watersheds and Big Lagoon have been grossly modified since European settlement beginning in the mid 1800's. Before this time the major human disturbance was from coastal Indians burning brush and grassland (e.g., Gordon 1987). The historic ecosystem was undoubtedly impacted and significantly structured by natural erosion, sediment deposition, flooding, drought, trampling and grazing by tule elk, and lightning fires. Nevertheless, human disturbances in the European period caused the most profound changes in watershed habitats and communities since sea level became relatively stable in the last few thousand years (e.g., Roundtree 1973, Atwater *et al.* 1979, Schwartz *et al.* 1986, Hornberger 1990).

Cattle grazing, logging and creek channelization and diversion were major causes of wetlands infilling. The result is more rapid drainage of water across a flatter and higher wetland landscape, and a dramatic decrease in riparian and low wetland habitats and biological communities. The major changes in wetland plant and animal communities are highlighted below.

### b. *Changes in Wetland Vegetation*

Since the 1850's, oral history, maps, and photographs document a striking decrease in the cover of native plant communities in the upland hills, along the riparian corridor, and in Big Lagoon. Riparian and wetland habitats were replaced by crop land and grazing land for dairies. This heavily altered landscape remained until after 1952, and up to 1970 in some places.

The hillside communities surrounding Big Lagoon were chronically overgrazed and trampled since the 1850's, resulting in extensive erosion, runneling and loss of productive topsoil. Much of the soil ended up in Big Lagoon. While in later years grazing was more controlled and finally ended in the late 1960's, the impacts were substantial and persistent. Even relatively recent aerial photos of the hillsides (1946-1970) show little shrubby cover. The cover of native perennial grasses was surely impacted early; they are preferred food of domestic livestock. More than other native upland vegetation, the native grasses were probably continuously suppressed by chronic grazing, trampling, and competition with introduced Mediterranean annual grasses.

The extreme human impacts on the Big Lagoon ecosystem may be best documented in a series of photographs taken from the northern hillside in the 1920's. These show the tidal lagoon in its present position, but all the wetland habitat inland of the lagoon was grossly modified. There was essentially no cover of native wetland plants throughout the entire tidal and freshwater lagoon. Big Lagoon was a large pasture cut by drainage ditches, Redwood Creek and Green Gulch Creek. This was also a period of regional drought, permitting even greater wetland conversion to drier land use. The photographs revealed no riparian trees or bushes in the Big Lagoon area.

The Big Lagoon freshwater pond and fringing marshes were converted to pasture by the turn of the century. This is clear in the 1920 photographs and persists in the aerial photographs from 1946 and 1952. In 1965, aerial photographs show well-organized patterns of ditches and rows indicating cultivated cropland in the pastures. Aerial photos from 1946 to the present show little change in the size of the surviving marsh area.

The riparian and willow forests became established along the present course of lower Redwood Creek only during the last three decades. Aerial photographs from 1946 and 1952 show the diverted creek course running through close-cropped agricultural lands, a setting consistent with observations of residents at the time. By 1965, photos show the double row of Monterey pines planted along the road, adjoining riparian trees, and some riparian trees or shrubs extending upstream. By then, the dense willow forest adjacent to the present parking lot was established in the area previously occupied by roads and buildings.

Plant communities in all the historic habitats of Big Lagoon have become increasingly dominated by alien species. Currently, of the 181 plant species recorded in all vegetation surveys (Table III-3), nearly half (45%) are non-natives. These alien-dominated habitats are highly visible. For example, intensive human disruption of the marsh adjacent to the current parking lot fostered the proliferation of the highly aggressive Kikuyu grass which invades this marsh on all sides. The riparian habitat has the lowest number of alien species, only about 31%. In contrast, about half of the species on both the upland disturbed habitats are aliens. The largest single habitat type at Big Lagoon is pastureland which is covered by nearly 100% alien species. Some of these plants were purposely introduced as pasture crops, but most are invasive weeds. Alien weeds often monopolize space and other resources, excluding natives plants perhaps as effectively as altered land forms and water flows. The plant communities at Big Lagoon therefore reflect both biological and physical changes caused by early agricultural practices.

The existing plant communities at Big Lagoon also reflect the recent change from an agricultural land use to public park (Figure III-6). Riparian forest now covers an altered stream course and adjacent drainage channel. This forest overlies the historic freshwater lagoon and fringing low wetland. A levee and walking path parallel the drainage channel also cutting across historic lagoon and wetland. The levee edges have been colonized by native riparian species, and planted with cottonwoods and native elderberry, and buckeye. Native upland species and alien weeds are interspersed with this riparian vegetation.

Horse-grazed pasture and a parking lot now cover the large, flat fill which was a large part of the historic freshwater lagoon, wetland, and riparian habitats along lower Green Gulch Creek. The pasture primarily supports non-native grasses and weeds, but some aquatic species live in the channels and lower pasture where water ponds. A parking lot overlies the historic sand dunes, lagoon, and wetland, and provides access to the beach and levee footpath via a pedestrian trail and bridge (Figure III-6).

Since the 1850's, the sand dunes along the shore of Big Lagoon were probably constantly trampled, subjecting loose sands to wind erosion and reducing dune vegetation to remnant patches. Ground photographs from the 1920's show a beach similar to today's: bare sand with hummocks topped with vegetation along the east end where bare sand extended to the base of the hillside.

c. *Changes in Wildlife*

The dramatic reduction of wetland area caused a parallel reduction in the number of species and population sizes of most if not all of the native wetland fauna. Animals living in the adjacent, highly disturbed upland habitats probably experienced the same reduction. All of the aquatic insects and amphibians are highly dependent on either running water, ponded water or wetland vegetation, which all became less frequent and widespread habitat features. The conversion of wetland to dry pasture undoubtedly had the most severe impacts on aquatic animals.

Amphibians may have been the animal group hardest hit by the land-use changes. There were probably healthy populations of red-legged frog inhabiting the freshwater lagoon at the convergence of Redwood and Green Gulch Creeks. Yellow-legged frogs would have been present in the faster-moving creekbeds and upper reaches of the creeks. Additionally, healthy populations of both Red-legged and Yellow-legged frogs could have been maintained in the riparian areas along the creeks. California and rough-skinned newts (*Taricha torosa* and *T. granulosa*, respectively) probably would have had larger populations due to the more numerous and larger areas of standing water for breeding sites. However, populations of upland species such as ensatina (*Ensatina eschscholtzi*), California slender salamander (*Aneides lugubris*) would not have been greatly altered from present conditions. Because they do not need standing water for reproduction and lay their eggs underground, the impacts of grazing do not significantly deter their numbers.

The large freshwater lagoon would have been prime pond turtle habitat, so turtle numbers would probably have been much higher. The vegetation cover in the riparian corridor would have provided cover for females on their way to nesting sites, resulting in more successful breeding.

Wetland bird species, whether year-round residents or visitors, lost virtually all habitat previously available for nesting and foraging at Big Lagoon by the turn of the century. In addition, several species were directly impacted by hunting. Snowy and Great Egrets were greatly reduced in number by hunters in the feather trade (Grinnell and Miller 1944). Black-shouldered Kite populations were significantly depressed through the early 1900's due to egg-collecting. Duck hunting along the coast of San Francisco Bay and Marin County in the late 1800's severely depleted populations of not only waterfowl, but shorebirds and rails (Grinnell *et al.* 1918). Many of the waterfowl populations were concurrently being depleted by wetland reclamation efforts which destroyed nesting habitat in the Sacramento-San Joaquin Delta (Herbold and Moyle 1989) and the rest of the San Francisco Bay region (Skinner 1962). Most raptors which were probably common prior to human settlement decreased significantly in number due to egg-shell thinning caused by high pesticide levels in prey, intentional poisoning by laced carcasses on ranchland, and shooting. Though these factors have been largely eliminated, many raptor species will probably not regain former abundances due to widespread and often irreversible habitat loss. Raptors significantly affected by these past human activities include Peregrine Falcons, Turkey Vultures, Osprey, Northern Harriers and Cooper's Hawks (see species accounts, Shuford 1993).

Uncontrolled and feral pets are a disturbance which were introduced incidental to the establishment of ranches and, more recently, residential development. Dogs and cats undoubtedly increase mortality and decrease the foraging time available to birds dependent on prey resources near or on the ground. They also decrease breeding success of ground- and near ground-nesting birds, including most wetland species. Feral cats may be particularly detrimental due to their secretive habits. However, it is unknown how the magnitude of these recently introduced disturbances are balanced by concurrent human-induced decreases in predation by bobcats, gray foxes, raptors and others.

Brewer's Blackbirds and Mourning Doves were probably uncommon members of the historic Big Lagoon avifauna. Today Brewer's Blackbirds are the most frequently observed bird species in the Big Lagoon area. Both species prefer foraging in open, sparsely vegetated ground, such as the heavily-grazed pastures and hillsides. Other new visitors include the introduced European Starlings and Rock Doves, which are common in disturbed landscapes including the pastures, hillsides, park facilities, residential areas, and so on.

### d. *Changes in Fisheries*

Although the stream itself is relatively undisturbed, some stream banks have been modified, increasing channel confinement along the flower fields. In Muir Woods National Monument downed trees and log jams were removed from the channel in the past. These management actions, which are no longer practiced, reduced pool frequency and depth. However, the stream channel of Redwood Creek, upstream of the beach area, is in generally excellent condition, with good pools, escape cover (root wads and undercut banks) and substrate free of excess sediment.

The major change in stream habitat conditions has been the loss of streamflow in the lower creek to domestic and agricultural diversions. An additional factor which has affected historic stream fish populations, has been the heavy harvesting of coho by sport and commercial fishermen. Steelhead and coho spawning runs are probably significantly smaller than in the past. However, at the present time, Redwood Creek has the southernmost healthy coho population in California.

The extensive modification of the lower river and lagoon has had more substantial effects. The present small estuary/lagoon lacks any calm-water refuge during major storms, and is inadequate to sustain tidewater goby. The small lagoon provides only limited summer rearing habitat for steelhead and may be too warm for coho. The small lagoon also provides only limited potential habitat for juvenile marine fish, such as staghorn sculpin or starry flounder. Perhaps most importantly, the small estuary probably does not provide a good brackish water transition zone for steelhead and coho smolts as they migrate through to the ocean. A brackish water zone is important in helping migrating smolts, especially smaller ones, gradually adjust to sea water before entering the ocean.

Two fish species introduced to San Francisco Bay, striped bass (*Morone saxatilis*) and yellowfin goby (*Acanthogobius flavimanus*), now rear in the lagoon. The goby also occurs in the stream immediately upstream of the lagoon. It is uncertain whether the goby is reproducing in the system, as the goby requires brackish water for spawning.

A pond in Green Gulch contains Sacramento perch (*Archoplites interruptus*), Sacramento blackfish (*Orthodon microlepidotus*), and prickly sculpin. The first two species are not native to Redwood Creek, and a few specimens of each have been collected in the creek, near the beach parking lot. The Sacramento perch and Sacramento blackfish are native to California, although the Sacramento perch is now nearly extirpated within its native range. Prickly sculpin are native to the creek, but if they were introduced to the pond from the same source as the blackfish and perch, they are probably the southern/inland subspecies, rather than the northern/coastal species found in the creek.